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A FLIGHT PERFORMANCE COMPARISON OF THE CURTISS P-40E WARHAWK AND THE MITSUBISHI A6M2 ZERO FIGHTERS

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Abstract

This paper compares the flight performance of the Curtiss P-40E Warhawk with that of the Mitsubishi A6M2[1] Zero, evaluating things like speed, climb rate, ceiling, sustained and instantaneous turn performance, dive, dive and zoom and energy retention. And that the P-40E was faster and dived better, and that the Zero climbed and turned better is by now accepted as common knowledge. But just how large was the difference? And is it possible to crown one as the overall better aircraft? This paper will attempt to get to the bottom of these questions using simulation results from a C++ computer program developed by the author.

Introduction

While the American Volunteer Group's (AVG) Curtiss P-40 Warhawks with their characteristic shark face painted on the nose is the aircraft most people associate as having combated the famous Japanese A6M2 Zero, it's not so certain that this actually happened. It's however a documented fact that what the AVG actually did face in numbers at the time were two other Japanese fighters, namely the Nakajima Ki-27 and the Ki-43.

50-cals serviced on AVG P-40E Warhawk somewhere in China

Photo: Wikimedia Commons public domain.

The Ki-27, which was codenamed Nate by the Allies, was an aircraft already bordering on obsolescence, equipped with a fixed landing gear and only capable of a modest 470 km/h. However, the AVG also faced a much more capable opponent, namely the Ki-43 Hayabusa, which was codenamed Oscar by the Allies. But even though it had a retractable landing gear and a more powerful engine, it was still a less capable aircraft than the Zero, and only managed a top speed of around 490 km/h compared to the Zero which was about 30 to 50 km/h faster depending on its power setting.

Side view of P-40E Warhawk carrying external drop tank.

Photo: NASA public domain.

A pair of Nakajima Ki-27's. Allied code name Nate

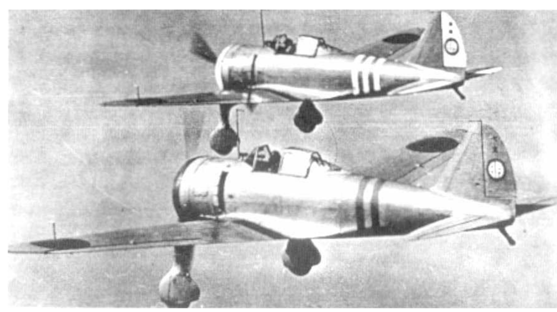


Photo: Wikimedia Commons public domain.

Nakajima Ki-43 Hayabusa. Allied code name Oscar

Photo: World War Photos public domain.

[1] Deciphering this Japanese designation code, the "A" meant Carrier based aircraft while the "6" that it was the sixth to be adopted. The "M" for Mitsubishi" and the "2" that it was the second version of this aircraft. Sometimes also referred to as the Reisen (Zero fighter) by Japanese pilots.

Captured Mitsubishi A6M2 Zero with US insignia. Allied code name Zeke

Photo: World War Photos public domain.

Taking a closer look at the two P-40's pictured above, we can see that they are both E-versions. This fact can be deduced by noting that they are both sporting a supercharger air intake located in close proximity to the propeller's spinner, and that they are both missing the two cowling machine guns mounted in the B and C versions and are instead equipped with an extra pair 50-cal heavy machine guns located in the wings.

Also note that the Oscar and Zero were quite similar in physical appearance, and given that the Zero later went on to become the most famous and well-known Japanese fighter of the war, it's then not so strange that many people would name the Zero as the Warhawk's main antagonist. And while it's not totally clear exactly when the paths of these two aircraft crossed for the first time, they certainly did combat each other later on in the war. Only some would claim that this was well after the AVG had been disbanded, and that the P-40's the Imperial Japanese Army Air Force (JAAF) and Imperial Japanese Nay (IJN) at this time encountered did not bear the Chinese national insignia as had been painted on the AVG's P-40's, but instead sported the white star of the United States Army Air Force (USAAF). However, even if the exact timing of when these two aircraft actually met for the first time may still be unclear, it still makes perfect sense to compare the P-40 to the Zero and not the Oscar, given that the Zero was a much more capable aircraft. Further, while the AVG certainly operated P-40-B's initially, they did later on receive E-versions as well, and which is why the comparison in this paper will be done assuming this more capable Warhawk version.

But returning to the question if General Chennault's AVG Flying Tigers P-40's ever encountered the A6M2 Zero in combat, there is at least one known case when a misidentification took place: This was on the 25th December 1941 when Japanese aircraft attacked Rangoon, and AVG P-40E pilots claimed that they had engaged "Zeroes", "Navy Zeroes" and "Model 0" escorts. However, records show that the Japanese fighter escort on that particular day was actually made up of only Ki-27's and Ki-43's, thus providing us with a clear example that Allied pilots sometimes mistook the Oscar for the Zero. And as an example of the above, here is an excerpt from the combat diary of AVG pilot William Reed from that day:

"I saw another P-40 who was also leaving the scrap. By now we were 140-150 miles across the gulf from Rangoon. I joined the other ship and saw that it was Dupouy. We started back across the gulf at 17,000ft, and had only gone about 30 miles out off the shore of Moulmein when we spotted three Model 0s in a V-formation below us, apparently heading home. We dropped down on their tails and surprised them. Dupouy was following me as I picked out the right-hand wingman. I fired from about 50 yards, and Dupouy fired behind me. The Jap exploded right in front of my face. I pulled sharply up to the right to avoid hitting him, and Dupouy pulled up to the left. In doing so, his right wing clipped the other Jap wingman's ship right in the wing root, and the Jap spun into the gulf, too."

So in summary, it's then not so strange that popular myth would have us believe that the P-40s of the Flying Tigers combated Zeroes, since this is what some AVG pilots themselves claim, even though we have evidence that they were actually prone to misidentify the Oscar as the Zero. On the other hand, there is one former Flying Tigers pilot who adamantly claims that they did indeed fight Zeroes in China: In e-mail correspondence sent in 1996 and 1997, former AVG pilot Erik Shilling refutes claims by historian Daniel Ford that there were no Zeros in China, and that General Chennault's lectures at Toungoo misidentified the Zero, mixing it up with the Hayabusa. However, Shilling dismisses Ford's claims, saying that he actually attended those lectures while Ford did not. In addition, there is actually a quote by Shilling in which he positively distinguishes between the Zero and the Hayabusa:

"Of all the fighter planes flown against the Japanese, the P-40 was the most under-rated airplane and the Japanese Zero was the most overrated. Contrary to popular belief, the P-40's larger turning radius did not present a problem when understood, and proper tactics were used against the Japanese fighters. Also its lower rate of climb could easily be overcome. The P-40 which was more than 40 mph faster than the Zero, could still climb at a speed that the zero was incapable of attaining. Pilots that tried to dogfight lost their lives. Whereas the hit and run tactic with a faster plane was the only way to fight the Hayabusa or Zero.
..The P-40's pilot protection was in the form of self-sealing fuel tanks. Almost two-inch thick bullet-proof armor plate windshields, and 9 mm and 7 mm armor plate protecting the pilot from behind. Also the P-40's armor plate could stop the bullets from any military aircraft the Japanese had in the China-Burma theater...Aviation buffs always come up with the statement that the Zero was more maneuverable than the P-40. Emphatically not true. Flown properly, the P-40 was an outstanding fighter..."

Leaving the Allied view of the war in the Pacific, and instead sampling some Japanese sources, in his memoirs[2] written after the war, the Zero's Chief Designer at Mitsubishi, Jiro Horikoshi, refers to a letter sent by a Vice Admiral in the IJN to the President of Mitsubishi, expressing thanks for the Zero, and crediting it with destroying 27 enemy aircraft in a battle over Chungking in China on the 13th September 1940. Consequently, it seems that Zero's had indeed been used in China prior to the AVG's first enemy contact on the 20th December 1941, and thus at least placing them in the combat theatre at the time, consequently making it theoretically possible that the AVG may indeed have encountered them just as Shilling and Chennault claim. But again, whatever the truth of this is, it's still a well-established fact that the P-40 actually did combat Zeroes later on in the war, and which is why these two aircraft's performance will be compared in this paper.

Concerning at what altitudes air combat in the Pacific usually took place at during this time period in the war, we can yet again take the Japanese attack on Rangoon on the 25th December 1941 as an example. And on that particular day, the Allies had Brewster Buffalo's stacked at 12,000, 17,000 and 20,000 ft (circa 3700, 4500 and 6100 m), while the AVG's P-40's flew at 18,000 and 20,000 ft (circa 5500 and 6100 m). Added to this we can note that even though the AVG's typical flying altitudes may have ranged from 15,000 to 20,000 ft, there are also examples of Japanese bomber missions flown as low as in the 5000 to 8,000 ft altitude band. Consequently, we can conclude that the intercepting fighters and escorts flew either below, or only marginally higher than their full throttle height (FTH), meaning that the single stage, single speed supercharged engines used on both the P-40E and the A6M2 at the time could in some sense still be considered as adequate. However, as the war progressed, the need for better performing engines was recognized, and later

[2] Eagles of Mitsubishi, Jiro Horikoshi, Kapps books 1970.

versions of both these aircraft were equipped with engines that had two-speed superchargers. In addition to this, later versions of the Warhawk were also equipped with license build Rolls-Royce Merlin engines that added a second stage to the supercharger as well. However, this paper will focus on the early stages of the war when both the P-40 and the A6M fighters were limited to single stage, single-speed supercharged engines.

Another interesting thing that can be deduced from historical record is that P-40E pilots who found themselves in a tight spot could actually extract much more power out of their engine than what was stated in the flight manual. And while this may not have been officially sanctioned at the time, it seems that pilots equipped with Allison V1710 powered aircraft nevertheless still discovered[3] that their engines could tolerate much higher boost levels than the manual stated without any obvious ill effects, something they were of course quick to exploit given the Zero's vast climb advantage under normal conditions. And as the performance charts below will illustrate, if a P-40E pilot actually utilized this non-sanctioned[4] "overboost" capability inherent in the Allison V1710 engine, he would not only have been significantly faster, but would also have been able to build up energy faster by out-climbing the Zero at lower altitudes. However, this of course goes against the grain and common knowledge which holds that the A6M2 Zero absolutely dominated the P-40E in all but speed and dive, but is nonetheless true as the performance charts below will show. But in order to distinguish between what was the ordinary performance limit and what could be achieved in an emergency, the performance data for both aircraft will be given both for the military power setting (MIL), and for the maximum war emergency power (WEP) setting. However, also note that even though the Sakae 12 engine is limited to a maximum of 2550 rpm according to Japanese sources, USN evaluation tests of captured specimens were still done at close to 2600 rpm, which even so seemed not to have had any negative impact on the engine.

Simulation assumptions

Below is a table summarizing the aircraft characteristics that have been assumed in C++ simulations:

Parameter	**P-40E Warhawk**	**A6M2 Zero**
Wing area total	21.93 sqrm	22.44 sqrm
Weight	3610 kg	2522 kg
Wing loading	164.7 kg/sqrm	112.4 kg/sqrm
Flat plate drag area (Cdo*S)	0.408 sqrm	0.462 sqm
Wing span	11.37 m	12.00 m
Span loading	317.5 kg/m	210.2 kg/m
Maximum lift coefficient on aircraft level	1.35	1.35
Sea level engine powers levels assumed	1050 hp at 3000 rpm 42" boost (Mil) and 1560 hp at 3000 rpm 60" boost (WEP) at SL	840 hp at 2500 rpm +150 mm (Mil) and 930 hp at 2550 rpm +250 mm (WEP) at SL
Power loading	2.31 to 3.44 kg/hp	2.71 to 3.00 to kg/hp
Weight/Flat plate drag area	8852 kg/sqrm	5456 kg/sqrm

For the P-40E, the speed and climb performance of the C++ model has been tuned to align with the numbers contained in a test trial report for a P-40E, GHQ-M-19-1320-A, dated 1st December 1941. In this the top speed was recorded to be 361.7 mph (582 km/h) at 15,000 ft and the climb time to this altitude 6.49 min[5] at a take-off weight of 7952 lb (3610 kg). The power figures for the engine come from Table II in the Allison Operation and Maintenance Handbook, ALD-3F2, dated 1st April 1943.

The Japanese flight manual for the A6M2 Zero states a maximum speed of 316 mph (508 km/h) with the Sakae 12 engine operating at +50 mm boost and 2350 rpms, and this data point together with power numbers from an original Japanese performance chart[6] for the Sakae 12 engine have been used to determine the Cdo for the Zero in the simulation model. However, in addition to this data from Japanese sources, there are also test results from US flight trials on a captured A6M2, as documented in report AFAMC-5 from 23rd October 1942 which states a maximum speed of 335 mph (539 km/h) at the FTH, and a sea level climb rate of 2710 fpm (13.8 m/s) with the engine operating at close to 2600 rpm and with 35" boost (+129 mm). And with the Cdo tuned according to the Japanese numbers, this US measured speed figure is in fact also replicated, thus adding further credence to the simulation model. However, it should here be pointed out that there are some uncertainties connected to the US speed values since these were not corrected for compressibility effects, meaning that these are probably somewhat optimistic, especially at higher altitudes, given that basically no correction at all is needed at sea level, but that this increases with altitude, probably reaching up to an about 5 km/h speed reduction needed at the FTH. Another fact hinting that this speed estimate may indeed be optimistic, is that another US test resulted in a top speed of only 328 mph for the Zero. However, there are also some people who suggest that both these numbers may instead be rather pessimistic, given that the US personnel doing the testing were not able to get to the full rated rpms from the engine initially, and had to move the pitch operating range of the propeller towards finer pitch to do so. And while some take this as evidence that the engine was damaged and not delivering to its full potential, it should here be noted that both tested aircraft's sea level climb rate was in the order of 2750 fpm (circa 14 m/s) which is not only replicated in the simulations, but is also just as expected based on their power loading. Consequently, a more likely explanation is that the original owners had done this pitch range adjustment prior to these aircrafts capture to cater for coarser pitch settings in order to improve the aircraft's range using the "low revs high boost, bring you home to roost" concept that Japanese fighter ace Saburo Sakai is credited with having introduced in the IJN.

But summing up on the simulation tuning with regards to speed for both the Zero and P40E, one can say that this has been done utilizing the highest values deemed reliable for both aircraft and can therefore in this sense be said to have been done fairly, albeit probably leaning more towards the optimistic.

Leaving the issue of speed performance modeling behind, and instead looking at aerodynamic properties, one thing that has proven elusive and difficult to pin down for both aircraft is the maximum lift coefficient, since there is to the author's best knowledge no firm data on this for either aircraft. But looking at wing profiles, we can conclude that the P-40E used the same type of NACA-profile as was used on the Supermarine Spitfire, namely the NACA 22-series. However, the Warhawk's wing was with its 15% thickness ratio at the root somewhat heftier than the Spitfire's 13%, but at the same time its tip was thinner, with only 9%, compare to the Spitfire's 9.4%. So interestingly, it seems that the P-40E actually had a thinner wing profile than the Spitfire at the tip which was somewhat unexpected, given that the Spitfire's wing was considered very thin even by the standards of the time. The A6M2 used a modified MAC 118 wing profile of 14.3 % thickness at the root, and the same profile but with a 9.4% thickness at the tip, meaning that it very much occupied a middle ground when it comes to the typical wing profile thickness ratios at the time. Consequently, there seems to be little to choose between the two aircraft's Clmax on wing profile level, and given that there is nothing remarkable about

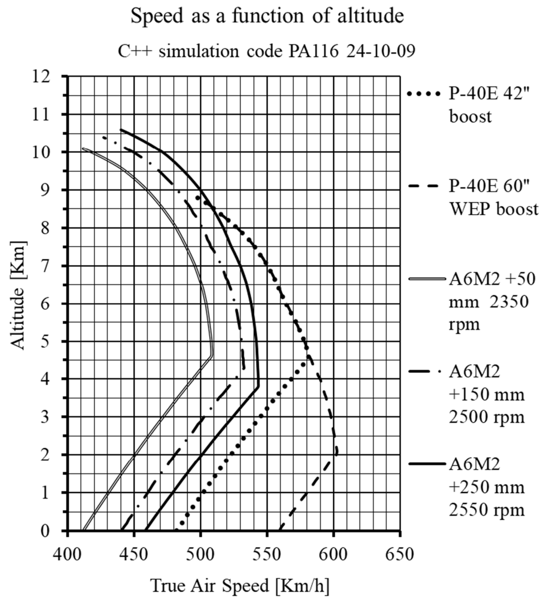
[3] See General Motors Corporation Allison Division letter from 12th December 1942 in in *Summary & summing up* chapter.
[4] The P-40E at the time was cleared for 42" of boost at MIL power. However, later in the war this was increased, and by the end of 1942 the officially sanctioned WEP was 60" boost .
[5] In the simulation, the climb time under these conditions is 6 m 44 s.

[6] Performance curve No. 1for Operational Engine Model 12, Engine Department, Aeronautical research Institute, 13th May 1939.

either aircraft's wing planform either, the Clmax on aircraft has therefore been assumed to be the same 1.35 for both aircraft, which in turn was a rather typical[7] value for this type of tractor powered aircraft at the time.

Speed performance

The figure below essentially speaks for itself, showing that the P-40E had a significant advantage in speed up until quite high altitudes. And given that the combat altitudes in the AVG's area of operations in general were from sea level up to around 20,000 ft (6100 m), we can see that the P-40E enjoyed a clear advantage over the A6M2 in this regard, irrespective of what boost levels are assumed.

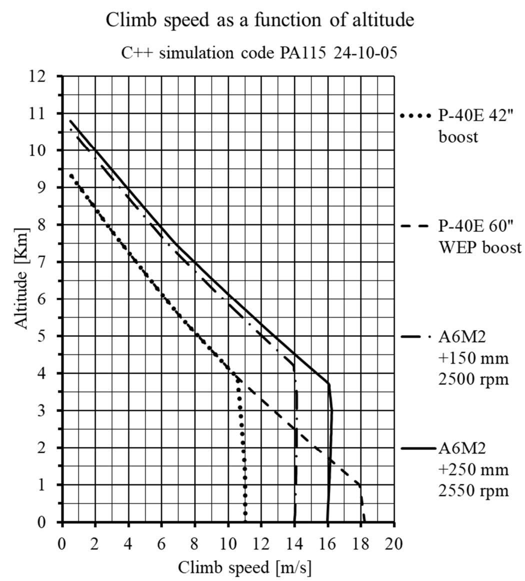


Even with a power setting as low as 42" boost, the P-40E was about 20 Km/h faster than the A6M2 from sea level all the way up to the Zero's FTH. However, above this altitude then the P-40E's advantage increased up to its own FTH, after which it lessened gradually, to finally cross over to the Zero's advantage when the altitude approached 9 km. However, if the P-40E pilot elected to increase the boost to 60", then the P-40E's speed advantage jumps to a staggering 100 km/h up to the Allison's FTH[8] of around 2000 m (circa 6560 ft). And as was previously discussed, 60" boost seems to have been well inside the engine's capabilities, and while the official clearance to go to such boost levels did not come until later in the war, it's even so highly likely that AVG pilots took advantage of this capability when pressed, or in order to catch up a Zero attempting to disengage.

So in summary, we can say that while the Zero certainly had some aces up its sleeve as well (as we shall see later), this huge speed advantage was the P-40E's primary asset when combating Zeros. Another advantage connected to speed that the P-40E held over the Zero, was that the Warhawk retained a high rate of roll even at higher speeds (which will be covered in more detail in a later chapter). However, connected to roll performance is also maneuverability. And on this point Erik Shilling can be said to go against the grain of what is commonly associated with the word, by claiming that the Warhawk was more maneuverable than the Zero. And at a first glance, many would probably call this an outrageous statement, given that most people associate maneuverability with an aircraft's low speed handling and turn performance. However, this is not Shillling's interpretation of what maneuverability means, and he instead connects it to the definition found in Webster's dictionary which is: *"an intended and controlled variation from a straight and level flight path in the operation of an airplane"*. And using this definition, the P-40 can certainly be said to be more maneuverable, since as long as the speed was above 175 mph IAS, then the Warhawk's higher[9] rate of roll meant it could change its direction of flight by altering the direction of the lift vector much faster than the Zero could, thus arguably making it more maneuverable. In addition, this was not only Shilling's view of what was important, since when interviewed, combat pilots of the time did not request improved turn performance, but invariably asked for better roll performance at higher speeds. To this can be added that during WW2, there was hardly any research work at all done at NACA to improve aircraft's turn rates, while an enormous amount of research[10] and flight trials were done in order to improve roll performance. And this work resulted in such innovations as the overhang balancing, Frise ailerons, servo- and spring tabs, internally balanced, beveled trailing edge and hydraulically boosted ailerons etc. However, none of this research work had yet been done when the AVG flew in China, and all these innovations still lay in the future, so it was therefore purely fortuitous for the Warhawk pilots that their planes were equipped with such well-functioning ailerons at the time.

Climb performance

In the figure below, we can see both aircraft's climb rate as a function of altitude at a number of different power settings.



A strong point for the P-40E is that it can still climb when the A6M2 is at its top speed, which is an observation that is valid from sea level all the way up to almost 9 km in altitude. And what this means in practice, is that a P-40E can maintain its distance from any pursuing A6M2 while at the same time adding energy by climbing. As an example, at 4500 m altitude, if the P-40E maintains the A6M2's top speed at this altitude it can still climb with an impressive 3 m/s (circa 600 fps). Consequently, a very useful and safe tactic for the P-40E would be to attack from an altitude advantage and then extend at a speed slightly higher than any pursuing A6M2 while still climbing, and then return and repeat the process as necessary when a sufficient altitude advantage has been built up. Properly executed, the A6M2 has basically no effective way to combat a P-40 E flown in this way since the P-40E can both attack with impunity, and then choose

[7] The Spitfire's Clmax on aircraft level is in the order of 1.36, as recorded in RAE R & M 2349, Notes on the Turning Performance of the Spitfire as Affected by Altitude and Flaps, M B Morgan & D E Morris, April 1941.

[8] The full speed critical altitude is increased substantially due to the ram air effect in the carburetor's intake.

[9] See roll rate versus speed chart on page 8.

[10] Much of this work was summed up in NACA report 868, Summary of lateral-control research, compiled by Thomas A Toll, which references an astounding 91 NACA reports on the subject!

to either repeat the process or leave the area depending on how the A6M2 pilots respond. And if the A6M2 pilots are foolishly aggressive, they may attempt to pursue the extending P-40E's, thus setting them up for a repeat attack. However, a more wisely flown A6M2 would on the other hand not pursue the P-40E's directly, but instead initiate a maximum rate climb. And since the A6M2's climb rate is so superior to the P-40E's as the figure above shows, the A6M2's could simply climb faster than the P-40E's, thus building up an energy advantage which would preclude the P-40E's from any repeat attack. But this is a rather passive response, since while it certainly saves the A6M2's from any repeat attacks, the Zero pilots cannot take the fight to the P-40E's unless the pilots of the latter are foolish enough to return to the fight without an altitude advantage.

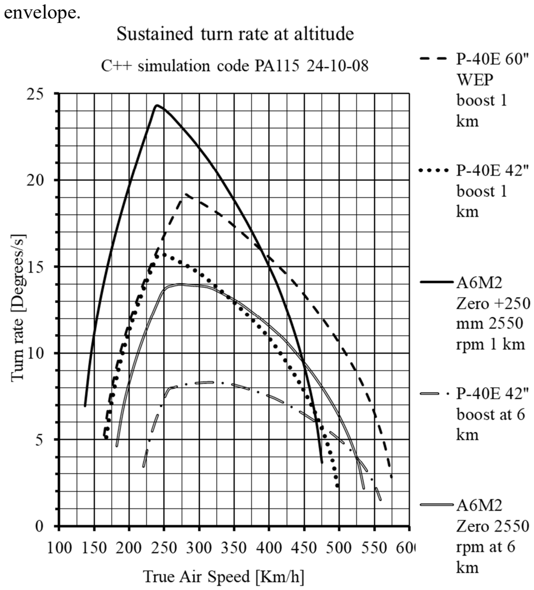
Another thing that we can conclude from the climb rate versus altitude chart is that at any altitude above 1500 m, then the Zero is vastly superior in climb. And what this means from a tactical perspective is that while a flight of Zeros cannot force un-cooperating P-40Es to do battle, they can however still dominate an area, as in establishing air superiority there, and leave any attacking P-40Es only a single slashing attack, after which they would be forced to leave given that the Zeros not only out-climb them, but have a higher ceiling as well. However, the above scenario of course assumes that the P-40Es had an altitude advantage to begin with, since they otherwise would be forced to leave the area immediately.

Turn performance

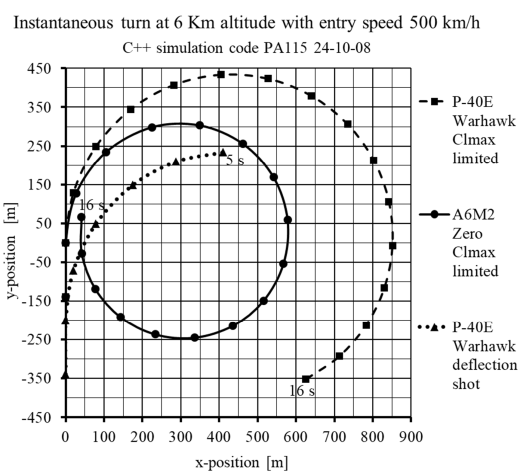
First of all, what is to be compared needs to be defined: There are a number of variables that can be measured when comparing turn performance, the most important being turn rate, turn radius and turn time. And while turn radius is sometimes also given in texts, it's most often the turn rate and not the turn radius which is mentioned, since this metric decides how fast an aircraft can change direction, and determines the other commonly used metric which is the turn time, i.e. the time it takes to complete a full 360 degree circle. Both these are then in turn (pun intended!) determined by the type of turn the aircraft enters, namely a sustained or an instantaneous turn:

The maximum sustained turn rate is defined as the highest turn rate an aircraft can sustain without losing speed. There are two main properties that limit the sustained turn rate: The first being the amount of lift the wing can produce for a certain amount of drag, and the other the engine power available to overcome this drag. The maximum instantaneous turn rate on the other hand, is the turn rate an aircraft can achieve without any concerns given to how fast it decelerates. In this case, the aircraft does not have the power to generate enough thrust to balance the increase in drag, and the pilot accepts a loss in speed in order to increase the turn rate to a value higher than the limit set by the sustained turn rate. The instantaneous turn rate is thus not limited by power, but either by the limit load factor, or if this is high enough, by the product of the aircraft's Clmax and the wing area.

Beginning with the P-40E's and Zero's sustained turn capabilities, below is a figure showing both aircraft's abilities at 1 km altitude. And as can be seen, the Zero is just as expected from the substantially lower span- and wing loading, the substantially better turning aircraft. However, as we can see, the P-40E's significantly lower power loading at its 60" WEP boost setting helps it lessen the gap somewhat, especially at higher speeds, where it's actually able to turn faster while still maintaining speed at airspeeds of 350 km/h (218 mph) TAS or faster. This is significant and bears pointing out, since 350 km/h (218 mph) TAS is not really very fast, and tells us that as long as the P-40E pilot keeps his speed up in the combat area, he does not have to worry about the Zero's better sustained turn capabilities at lower speeds. However, this observation is of course only valid at lower altitudes, since at higher altitudes, the Zero will absolutely dominate the P-40E in sustained turns given that the Zero not only gains in absolute numbers, but also maintains this superiority over almost the complete speed envelope.



Taking our leave of sustained turn performance, below is a figure showing how these two aircraft compare when it comes to instantaneous turns, with time markers on both curves spaced 1 s apart. And as can be seen, it takes the Zero about 16 s to perform a complete 360 degree turn under these conditions, with the speed having been reduced to 346 km/h at the end point. The P-40E on the other hand has not even completed three-quarters of a turn at this point, and in order to complete a full 360 degree turn under these conditions the P-40E needs an additional 9 s for a total of 25 s, at which time its speed has dropped off to 335 km/h.



Concerning the g-loads in these turns, the Zero can maintain around 6 g (the assumed maximum) for the first couple of seconds only, after which it drops off to end at around 3.6 g's at the 16 s endpoint. The maximum g-load on the Warhawk has also been assumed to be 6 g's, but the dynamic pressure resulting from 500 km/h TAS at 6 km altitude is not enough to sustain this, and the Warhawk starts off its instantaneous turn at only around 4.4 g, which then gradually drops off to circa 2.8 g's at the 16 s endpoint in the figure.

However, a pursuing P-40E trailing a Zero can even so still achieve a fleeting guns solution even if the Zero executes a break turn as depicted by the solid line above. And in this example, the P-40E, as captured by the dotted line, is attacking the Zero from a position 200 m behind and from this position still able to attain

a firing position even though the Zero executes a maximum rate instantaneous turn. In fact, as the example shows, the P-40E can under these conditions maintain enough deflection to shoot for the first 5 s of the Zero's break turn. And theoretically, this should be more than enough for the P-40E's six 50-cal's to do the job. But if not, and the P-40E pilot misses the shot, then he must of course avoid any temptation to try to turn with the Zero and instead reverse his turn and use his superior speed and diving capability to extend away. Note that the speed of both fighters at 5 s into this instantaneous turn has dropped to be in the order of 450 km/h (280 mph), and that their respective maximum roll rates at this speed are in the order of a 100 deg/s for the P-40E, while the Zero can only manage about 25 deg/s (See roll rate figure on page 7), thus allowing the P-40E to keep out of the Zero's plane of attack by utilizing its advantage in roll, while at the same time using its superior speed capability to extend away.

Looking at the reverse situation, i.e. if a P-40E pilot is bounced by a Zero, the former must at all costs avoid the natural instinct to do a tight break turn into the attack, but should instead roll into the opposite direction and dive away while continuously utilizing the P-40E's superior roll capability to stay out of plane from the Zero, thus denying the latter a guns solution while at the same time gradually building up a speed advantage which will in the end provide the P-40E pilot with enough separation to be able to safely extend away.

Leaving turn performance behind, and before taking a closer look at dive performance, it should be noted that since this paper is focused on flight performance, the important aspect of armament can here only be mentioned in passing. And beginning with the P-40E, we can conclude that it was armed with six 50-cal M2 Browning heavy machine guns with 235 rounds per gun, all placed in the wings outside the propeller arc while the A6M2 Zero had two synchronized 7.7 mm Type 97 machine guns, each with 500 round per gun firing through the propeller arc, and two Type 99-1 license built 20 mm Oerlikon FF cannons with 60 shells per gun placed in the wings outside the propeller arc. This means that on paper, both aircraft could be said to be quite well armed for the time. However, while the P-40E's armament was quite well suited to combat both contemporary Japanese bombers and fighters, the A6M2's armament must on the other hand be said to have been better suited for intercepting bombers than combating fighters: This is because dogfighting is often characterized by fleeting high deflection snap shots, and in such situations a high muzzle velocity combined with high hitting power and a high rate of fire is a valuable asset, all of which the M2 Browning delivered. The Type 99 cannon on the other hand, while certainly hard hitting when its shells connected, was still hampered by a low muzzle velocity, a mediocre rater of fire, and most importantly of all, was limited to only a few seconds (circa 7 s) of firing time. This latter point was a big drawback for the A6M2 when it came to combating American fighters, since the latter were in most cases both adequately armoured and equipped with self-sealing fuel tanks. This in turn meant that downing an aircraft like the P-40E became a very difficult proposition indeed once the A6M2 pilot had expended his cannon ammunition and was left only with its rifle-caliber machine guns.

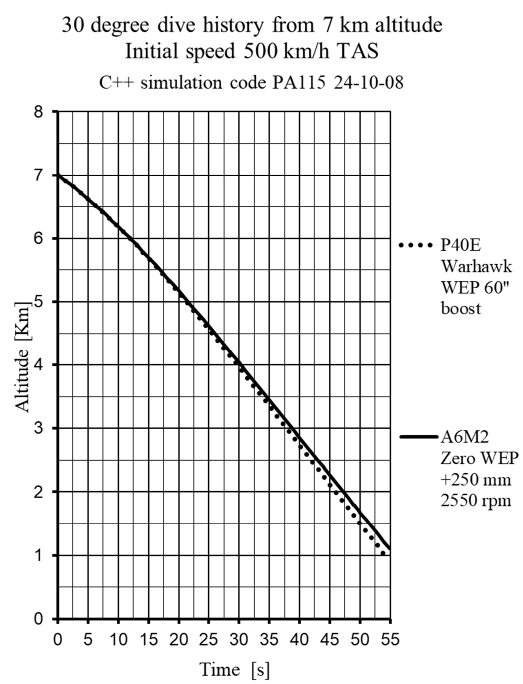
Diving performance

When analysing dive performance, a good starting point is to begin by looking at the forces acting on the airplane, i.e. the thrust and the drag, denoted T and D respectively, and the component of the weight (m·g) acting in the direction of the dive. These can then be divided by the mass m, to derive the dive acceleration a:

Equation[11] governing dive acceleration: $a = \frac{(T-D)}{m} + g \cdot \sin\gamma$

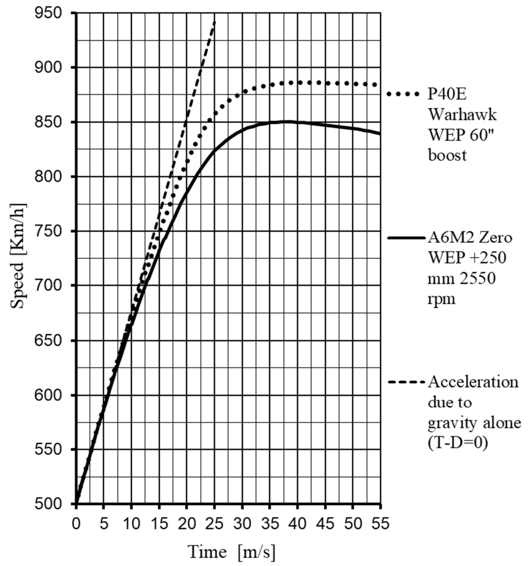
[11] Equation derived in the book *WW1 Aircraft Performance*, by Anders F Jonsson, Lulu Press Inc, January 2023.

The way this equation is structured is quite useful, since it tells us that the effects of gravity on acceleration (the second part of the equation) is independent of mass, i.e. a large mass is no advantage per see, and can in fact quite to the contrary be a burden in some cases as will be outlined below. Moving on to the first part of the equation, we see that the mass appears in the denominator meaning that as the mass increases, then the effects of both thrust and drag upon the acceleration is diminished. The above reasoning brings us to the important conclusion that as long as the thrust is larger than drag, then mass is a hindrance, but as soon as drag becomes larger than thrust, then mass becomes an asset in that it decreases the negative effects of drag and consequently allows a heavy fighter to accelerate better in a prolonged dive since the accelerating due to gravity is not as negatively impacted as it is for a lighter fighter. This is an important observation, since it tells us that the advantage a heavy aircraft holds over a lighter is not that it will accelerate better due to more mass, but that the detrimental effects of drag will be reduced by the heavier mass making the heavy aircraft's acceleration more closely approach the theoretical maximum as limited by the earths gravitational constant g. Summing up, we can conclude that given two fighters with similar power and drag characteristics, we should expect to see the lighter fighter accelerate better in the initial, and the heavier fighter better in the latter stages of the dive . Leaving this theoretical analysis of general dive behaviour behind, and instead looking at the results from the P-40E and Zero dive simulations below, we can see that the P-40E is just as we would have expected from theory the better performing aircraft in a prolonged dive.

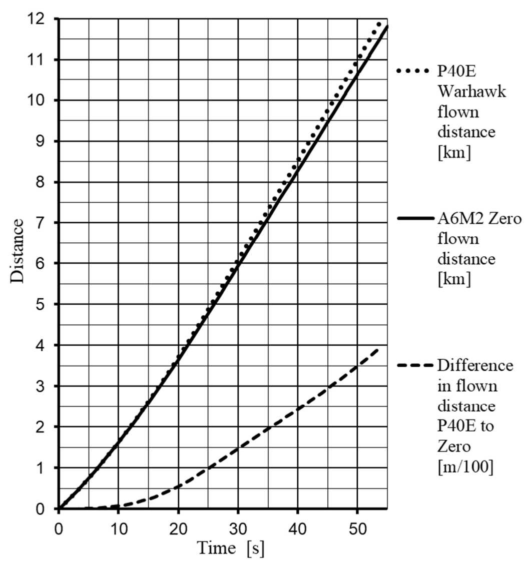


In this scenario, both aircraft start off at the same speed and altitude, i.e. at 500 km/h TAS and at an altitude of 7000 m from which they both enter into a 30 degree dive. The reason for choosing this rather moderate dive angle is that this allows more time for any differences between the aircraft to build up than would have been possible if a steeper dive angle had been chosen. The simulation is then halted when the first aircraft reaches an altitude of 1000 m. And just as expected, the P-40E is the first aircraft to reach this altitude, which occurs at 54 s into the dive and with a speed of 884 km/h TAS. At this point in time the Zero is still at an altitude of 1200 m and trailing circa 400 m behind, and with a speed that is circa 45 km/h slower than the Warhawk.

30 degree dive history from 7 km altitude
Initial speed 500 km/h TAS
C++ simulation code PA115 24-10-08



30 degree dive history from 7 km altitude
Initial speed 500 km/h TAS
C++ simulation code PA115 24-10-08



And in the two figures above, we can see that there is basically no difference in acceleration and distance between the aircraft for the first 10 s. The reason for this is because that in the initial stages of the dive, the acceleration due to gravity, which is around 4.91 m/s^2 at this dive angle, is so much greater than the acceleration due to thrust which is circa 0.15 m/s^2 for the P-40, and circa 0.21 m/s^2 for the A6M2. Note that this means that the Zero initially accelerates slightly better which may at first seem counterintuitive, but is of course due to its lower power loading, and is in fact just as predicted by the dive acceleration equation.

However, at around 10 s into the dive the speed has built up to such an extent that the drag starts to become larger than the thrust. And as we can see from the figures above, this affects the Zero to a much larger degree than the P-40E which is also just as expected, given that its weight to flat plate drag area ratio is only about 60% of that of the Warhawk's. This in turn explains why the separation distance just keeps on increasing and why the Zero lags further and further behind as the speed difference between the two increases even more. Another interesting thing that can be seen in the figures is that both aircraft reach terminal velocity for this dive angle circa 35 s into the dive, and that the airspeed stabilizes at around 880 km/h TAS for the P-40E, while the Zero's terminal velocity under these conditions is around 30 km/h slower.

Summing up on dive performance, we can conclude that diving away is no guaranteed "get out of jail free" card even for an aircraft as superior in dive as the P-40E. Because as we can see from the simulations, there is basically no increase in separation between the two aircraft for the first 10 s of the dive. This in turn means that the P-40E pilot cannot let his speed down and let the Zero too near him in the first place, but has to have the discipline to disengage early already at a safe distance outside the Zero's effective guns range given that from whatever distance the disengagement is initiated from, it will take the P-40E close to 40 s to build up even such a moderate additional separation distance as 250 m.

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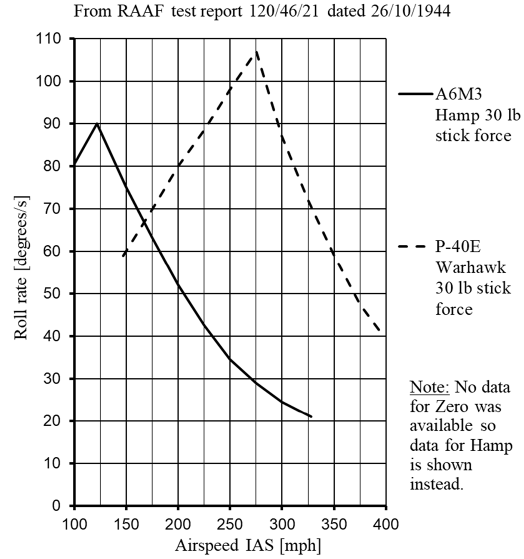
Tactics

While neither aircraft would be in a good position if attacked from above by an enemy with an altitude advantage, their options under such conditions are rather different: The P-40E pilots (provided the Zeros are seen in time) can always escape using their superior speed and diving capabilities. In addition, even if the A6M2s manage to catch up, the P-40E pilots can as a second line of defense use their superior roll capabilities at higher speeds to continuously adjust their trajectory so that the A6M2's pilots are denied an opportunity to open fire. Note that this does not necessarily have to mean that the P-40E actually out-turns its opponent, but rather that it can enter and reverse its direction of turn much faster than a Zero a higher speeds. Because as the roll rate as a function of speed figure below shows, if this is done at any speed higher than 175 mph IAS then the A6M2's aileron stick force will be so high that the pilot has no way of following such maneuvering, and would eventually be forced to break off the chase.

P-40E Warhawk and A6M3 Hamp roll rate data
From RAAF test report 120/46/21 dated 26/10/1944



Connected to roll performance, it should be mentioned that there is also another RAAF report[12] which also covers roll, and that in this document the A6M3 Hamp is credited with a higher maximum roll rate, namely 105-110 deg/s at 175 mph IAS (depending on roll direction) with a 50 lb stick force. But since I

[12] Brief flight trials of Japanese fighter type 0 Mk.II S.S.F. Hap, 119/A/30, 16th October 1943.

have no such figures for the Warhawk, only the curves for a 30 lb stick force were included in the figure. However, it should here be noted that even if this limit was to be increased by another 20 lb to a total of 50 lb, then the Warhawk would still retain its roll advantage over the Hamp at speeds over 200-225 mph.

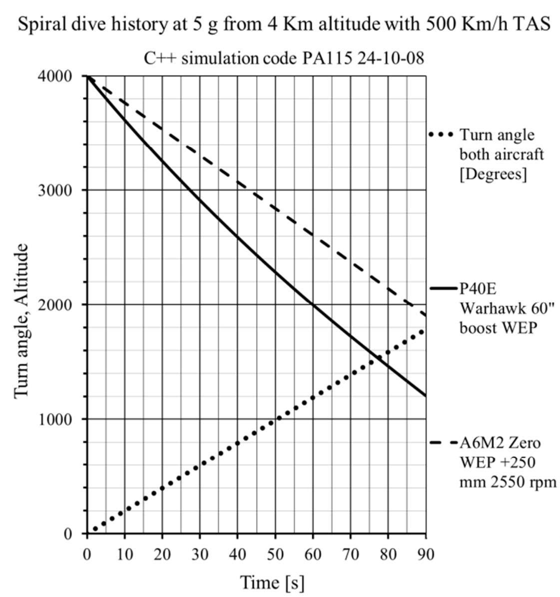
And when one sees the figure above, one is of course immediately struck by the large difference in roll performance, and that IJN pilots found this situation acceptable. However, it should in this context be mentioned that Japanese designers seem to have been aware of the problem and were looking into ways of alleviating it. In fact, Jiro Horikoshi's memoirs contain references to this problem and mentions that various means to rectify this were considered. One idea was to go with a servo tab based solution to combat the high stick forces, and this design was actually flight trialed as well. But based on the test pilot's testimony Horikoshi mentions in the book, the wing skin[13] wrinkled during the testing, indicating that the Zero's light wing design was simply not stiff enough to handle the high torsional loads resulting from the tab boosted ailerons. However, it seems that additional design efforts were undertaken, and Horikoshi in his book mentions that a thickened wing skin was actually tried, but that following a prototype crash which killed the test pilot, the servo tab idea was in the end abandoned. Nevertheless, this story still goes to show that the Mitsubishi designers were well aware of the Zero's roll rate problem, and even though the solution seems to have eluded them, it still shows that Mitsubishi did try to address the problem even though no production Zeros were ever equipped with a servo tabs during the war. My own personal theory of why this did not come about is that the aileron reversal speed on the Zero was simply too low: Because given that the reversal speed on the Spitfire MkI was as low as 480 mph, and that it only retained 35% of its roll capability at 400 mph[14], it's highly likely that the Zero's aileron reversal speed and rolling capability at high speeds was even lower. And if this was the case, then the only thing a servo tab would really have accomplished, would be to twist the wing without much of a gain in roll rate even though the deflection of the ailerons themselves may have been increased. Consequently, it's quite likely that the designers at Mitsubishi concluded that a servo tab would be useless unless a major redesign to stiffen up the whole wing was undertaken. As it was this was never done, probably due to the huge engineering effort needed in combination with the prohibitive impact on aircraft production this would have entailed.

Leaving the comparison of the P-40E's and Zero's roll performance behind, and instead doing a more general comparison of these two aircraft, we can conclude that this paper's comparison of the P-40E versus the A6M2 in some sense showcases why the trend during WW2 moved towards ever faster aircraft at the cost of dogfighting and turn capability as represented by the A6M2. Because while the former could always take the fight to the latter, this was not an option for pilots flying the typical Japanese fighters at the time since they would only be presented with an opportunity to do battle when the pilots of the faster US aircraft chose to do so. Granted, the A6M2 was still the better climbing aircraft, so at least it retained that capability over the P-40E. However, it here bears pointing out that a design that favours speed does not necessarily have to have a poor climb capability, since this is more dependent on the power loading W/P than the wing loading W/S. A good example of this is the German Bf-109, which combined both high speed and good climbing capability in the same aircraft. But this was not because if its wing loading, but rather because it had a very good power loading. And while aircraft with a low wing loading in many cases climb well, the advent of the variable pitch propeller meant that also higher wing loaded aircraft could deliver good climb performance. Because what happens if the wing area is reduced (assuming the power and weight remain about the same), is simply that the speed for best climb rate is moved to a somewhat higher value, and in this case the variable pitch propeller ensures that the propeller efficiency still remains about the same at this higher speed, meaning that the climb rate is basically maintained. A good practical example of this can be seen in a Spitfire turn performance study[15] made by the British during WW2, which showed that while the turn performance certainly would be negatively affected if the wing loading went up to match the Bf-109's, the Spitfire's climb rate would remain about the same up to around 7600 m (25,000 ft) even if the wing area was reduced by as much as 25%! And since such a drastic reduction of the wing area would have resulted in a significant increase in both speed and dive performance, it's then not so strange that the trend during the war went inexorably towards ever higher wing loadings in the new designs[16] that were being fielded at the time.

Finally, and to sum up on climb performance, we can note that it was not the fact that the P-40E was designed with speed in mind (i.e. a higher wing loading) that made it climb worse than the A6M2, but rather that it was so much heavier, which in turn resulted in a higher power loading.

Energy retention

In the figure below, both aircraft start off at an altitude of 4000 m, maintaining a load factor of 5 g at a constant speed of 500 km/h TAS. And since neither has the power to maintain 5 g's at this speed, both aircraft need to make up for the power deficit by descending. This will lead to a so-called spiral dive, and since both aircraft maintain the same speed and load factor, their turn rates will be the same and can thus be represented by the same line in the figure, which also shows that they can manage to complete almost five complete circles (1800 degrees) in 90 s if these flight conditions are kept constant. And as can be seen, the Zero has a much better energy retention, losing altitude at a significantly lower rate than the Warhawk, which results in that after 90 s into the spiral dive, then the Zero is still at an altitude of circa 1900 m while the Warhawk has lost 700 m more, ending up at about 1200 m.



[13] The aluminium skin thickness on the Zero was extremely thin, with some parts being only around 0.02" (0.51 mm) thick according to some US sources.
[14] RAE R & M 2507, Aileron tests on a Spitfire, D E Morris, M D Morgan and F Grinsted, April 1941.
[15] RAE R & M 2349, Notes on the Turning Performance of the Spitfire as Affected by Altitude and Flaps, M B Morgan & D E Morris, April 1941.
[16] While the increased wing loading for the Bf-109 and Spitfire certainly was due to weight creep, both the Martin Baker M.B.5 and Supermarine Spiteful bears witness to this trend since they were designed with a high wing loading from the very onset.

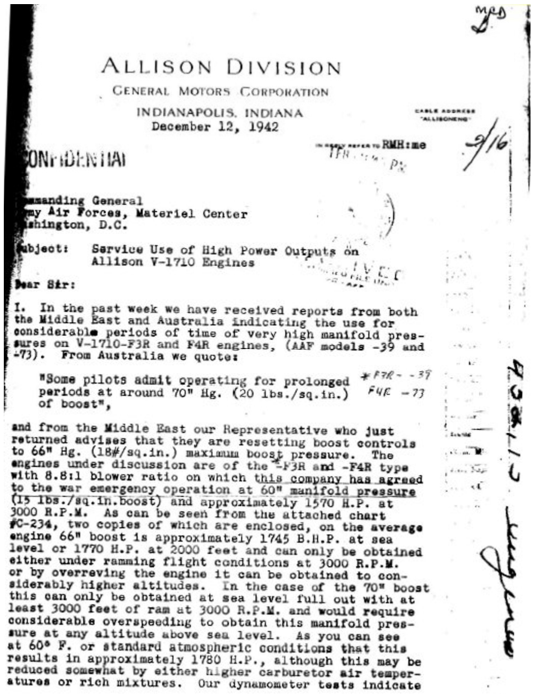
What this means in practice is that the Zero can maneuver more extensively and yet still retain more of its energy compared to the Warhawk. Therefore, if the latter still elects to pursue a prolonged high g turn fight, then this means that it will inevitably end up with an altitude disadvantage. Consequently, the only options open to the Warhawk is either to begin the fight with an altitude or speed advantage, or to avoid combat altogether and extend away from the Zero. However, it should here be noted that the Warhawk's superiority in roll essentially negates the Zero's energy retention advantage, since the Warhawk pilot can at any time in a high speed spiral dive reverse the direction of turn and lose the Zero, given that the Zero has no chance at all to stay in plane with the Warhawk due to its extremely high aileron stick forces at these speeds. And returning yet again at the roll rate chart, we can see that the P-40's roll rate is about three times higher than that Zero's at these speeds (500 km/h TAS is circa 256 mph IAS at 4 km altitude).

Finally, please note that this scenario was simulated solely to compare the aircraft's properties in high speed, high g-load conditions, and is not really a realistic combat scenario as such given that it's highly unlikely that any pilot would fly for such an extended period of time at such a high g-loads, and that the simulation scenario was run only with the intention to highlight each aircraft's energy retention capabilities, and nothing else.

Summary & summing up

While historical record for the most part seems to confirm that the AVG to a large extent used the tactics that could be expected based on the simulation results, i.e. flew the P-40 to its strengths and stayed high and fast and avoided any prolonged dogfighting with their more nimble adversaries like the Hayabusa and Zero, the simulation nevertheless show that it also had the ability to out-climb the Japanese fighters at lower altitudes if the P-40 pilots utilized the Allison's at the time unsanctioned, yet still available over-boost capability. However, if any AVG pilot ever played the P-40 to its strengths down low in this way remains unknown to the author. But it's still interesting to note that the P-40 seems to have had that capability, and that it was not only limited boom and zoom tactics when combating contemporary Japanese aircraft, but could also in some sense reverse the tables down low, besting the Zero by out-climbing it and then using its energy advantage to swoop down, trading height for turn rate, and thereby achieve a firing position. And considering the P-40's impressive armament of six fast-firing and hard-hitting 50-cals, a brief defection shot was all that was needed to down a fragile Zero without self-sealing fuel tanks and no armour protection to speak of.

Consequently, we can in summary say that this analysis shows that while the AVG certainly were wise to fly the P-40 to its strengths using boom and zoom tactics, it was by no means a one-trick-pony because as the simulations show, it could also best the Zero at low levels by out-climbing it using the Allison's impressive, albeit not at the time officially sanctioned high boost power capabilities. And it should in this context be noted that as long as the pilots made judicious use of this capability, it seems to have been well within what the engines actually could handle, since as the document below shows, by the end of 1942 the use of boost as high 60" was actually officially cleared as WEP.



ALLISON DIVISION
GENERAL MOTORS CORPORATION
INDIANAPOLIS, INDIANA
December 12, 1942

RMH:me

CONFIDENTIAL

...manding General
...my Air Forces, Materiel Center
...shington, D.C.

Subject: Service Use of High Power Outputs on Allison V-1710 Engines

Dear Sir:

I. In the past week we have received reports from both the Middle East and Australia indicating the use for considerable periods of time of very high manifold pressures on V-1710-F3R and F4R engines, (AAF models -39 and -73). From Australia we quote:

"Some pilots admit operating for prolonged periods at around 70" Hg. (20 lbs./sq.in.) of boost",

and from the Middle East our Representative who just returned advises that they are resetting boost controls to 66" Hg. (18#/sq.in.) maximum boost pressure. The engines under discussion are of the -F3R and -F4R type with 8.8:1 blower ratio on which this company has agreed to the war emergency operation at 60" manifold pressure (15 lbs./sq.in.boost) and approximately 1570 H.P. at 3000 R.P.M. As can be seen from the attached chart #C-234, two copies of which are enclosed, on the average engine 66" boost is approximately 1745 B.H.P. at sea level or 1770 H.P. at 2000 feet and can only be obtained either under ramming flight conditions at 3000 R.P.M. or by overreving the engine it can be obtained to considerably higher altitudes. In the case of the 70" boost this can only be obtained at sea level full out with at least 3000 feet of ram at 3000 R.P.M. and would require considerable overspeeding to obtain this manifold pressure at any altitude above sea level. As you can see at 60° F. or standard atmospheric conditions that this results in approximately 1780 H.P., although this may be reduced somewhat by either higher carburetor air temperatures or rich mixtures. Our dynamometer tests indicate

Author

Anders Jonsson holds a Master of Science degree in aeronautical engineering from the Royal Institute of Technology in Stockholm, Sweden, specializing in aerodynamics and structural engineering. He has recently retired, after a career spanning more than 35 years, most recently working in the telecommunications industry with 3G, 4G and 5G mobile systems research and development at Ericsson.

Prior to that he worked in the Swedish defence industry with systems, aerodynamics and systems engineering, project management and marketing for various Ericsson and SAAB owned companies working with electronic warfare and training systems both for vehicular and aircraft applications including the jamming pods U22, U25, U95 and the electronic countermeasures suites for the AJ37, JA37 Viggen and JAS39 Gripen aircraft.

Afterword

This paper contains a lot of simulation results and historical data, some of which may need to be revised at a later date. And if this proves to be the case, then the plan is that these updates will be posted under the documents tab on my website:

https://militaryaircraftperformance.com

Finally, if you have any questions or would like to give some feedback on this paper, then you can get in touch with me via the contact form that can be found on the same website. In addition, please note that you can find other papers I have written on this website (downloadable for free), and that I have also written a book on the subject of WW1 aircraft performance and design, more information about which can also be found on my website.

Revision handling and changelog

First revision: Compiled the 9th November 2024.